

$\mathcal{B}(D_s^+ \rightarrow \ell^+ \nu)$ and the Decay Constant $f_{D_s^+}$

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Abstract. I report final CLEO-c results on the purely leptonic decays of the $D_s^+ \rightarrow \ell^+ \nu$, for the cases when ℓ^+ is a μ^+ or τ^+ , when it decays into $\pi^+ \bar{\nu}$ using 314 pb^{-1} of data at 4.170 GeV. I also include preliminary results from the $\tau^+ \rightarrow e^+ \nu \bar{\nu}$ channel using 195 pb^{-1} . Combining both we measure $f_{D_s} = 275 \pm 10 \pm 5$ MeV, and $f_{D_s^+}/f_{D^+} = 1.24 \pm 0.10 \pm 0.03$.

1. Introduction

To extract precise information from $B - \bar{B}$ mixing measurements the ratio of “leptonic decay constants,” f_i for B_d and B_s mesons must be well known [1]. Indeed, measurement of $B_s^0 - \bar{B}_s^0$ mixing by CDF [2] has pointed out the urgent need for precise numbers. The f_i have been calculated theoretically. The most promising of these calculations are based on lattice-gauge theory that include the light quark loops [3]. In order to ensure that these theories can adequately predict f_{B_s}/f_{B_d} it is critical to check the analogous ratio from charm decays $f_{D_s^+}/f_{D^+}$. We have previously measured f_{D^+} [4, 5].

In the Standard Model (SM) the D_s meson decays purely leptonically, via annihilation through a virtual W^+ . The decay width is given by [6]

$$\Gamma(D_s^+ \rightarrow \ell^+ \nu) \frac{G_F^2}{8\pi} f_{D_s^+}^2 m_{\ell^+}^2 M_{D_s^+} \times \left(1 - \frac{m_{\ell^+}^2}{M_{D_s^+}^2}\right)^2 |V_{cs}|^2, \quad (1)$$

where m_{ℓ^+} and $M_{D_s^+}$ are the ℓ^+ and D_s^+ masses, $|V_{cs}|$ is a CKM element equal to 0.9737, and G_F is the Fermi constant.

New physics can affect the expected widths; any undiscovered charged bosons would interfere with the SM W^+ [7]. These effects may be difficult to ascertain, since they would simply change the value of f_i extracted using Eq. (1). We can, however, measure the ratio of decay rates to different leptons, and the predictions then are fixed only by well-known masses. For example, for $\tau^+ \nu$ to $\mu^+ \nu$ the predicted ratio is 9.72; any deviation would be a manifestation of new physics manifestly violating lepton universality [8].

2. Experimental Method

In this study data collected in e^+e^- collisions using the Cornell Electron Storage Ring (CESR) and recorded near 4.170 GeV. Here the cross-section for $D_s^{*+} D_s^- + D_s^+ D_s^{*-}$ is ~ 1 nb. We fully reconstruct one D_s as a “tag,” and examine the properties of the other. In this paper we designate the tag as a D_s^- and examine the leptonic decays of the D_s^+ , though in reality we use

both charges. For studies with D_s^+ decaying into a $\mu^+\nu$ or $\tau^+\nu$; $\tau \rightarrow \pi^+\bar{\nu}\nu$ ($\pi^+\bar{\nu}\nu$) we use 314 pb^{-1} of data; for $\tau^+ \rightarrow e^+\bar{\nu}\nu$ ($e^+\bar{\nu}\nu$) we use 195 pb^{-1} .

The analysis for $\mu^+\nu$ and $\pi^+\bar{\nu}\nu$ has already been published [9]. In summary tags are created from several modes including $K^+K^-\pi^-$ (13871 events), $K_S^0K^-$ (3122), $\eta\pi^-$ (1609), $\eta'\pi^-$ (1196), $\phi\rho^-$ (1678), $\pi^+\pi^-\pi^-$ (3654), $K^{*-}K^{*0}$ (2030) and $\eta\rho^-$ (4142), a total of 31302 tags. When the tagging γ from the D^* decay is also required, the number of tags is reduced to 18645.

Candidate $D_s^+ \rightarrow \mu^+\nu$ events are searched for by selecting events with only a single extra track with opposite sign of charge to the tag; we also require that there not be an extra neutral energy cluster in excess of 300 MeV. Since here we are searching for events where there is a single missing neutrino, the missing mass squared, MM^2 , evaluated by taking into account the seen μ^+ , D_s^- , and the γ should peak at zero, and is given by

$$\text{MM}^2 = (E_{\text{CM}} - E_D - E_\gamma - E_\mu)^2 - (-\vec{p}_D - \vec{p}_\gamma - \vec{p}_\mu)^2, \quad (2)$$

where E_μ (\vec{p}_μ) is the energy (momentum) of the candidate muon track.

We also make use of a set of kinematical constraints and fit the MM^2 for each γ candidate to two hypotheses one of which is that the D_s^- tag is the daughter of a D_s^{*-} and the other that the D_s^{*+} decays into γD_s^+ , with the D_s^+ subsequently decaying into $\mu^+\nu$. The hypothesis with the lowest χ^2 is kept. If there is more than one γ candidate in an event we choose only the lowest χ^2 choice among all the candidates and hypotheses.

The kinematical constraints are the total momentum and energy, the energy of the either the D_s^* or the D_s , the appropriate $D_s^* - D_s$ mass difference and the invariant mass of the D_s tag decay products. This gives us a total of 7 constraints. The missing neutrino four-vector needs to be determined, so we are left with a three-constraint fit. We perform a standard iterative fit minimizing χ^2 . As we do not want to be subject to systematic uncertainties that depend on understanding the absolute scale of the errors, we do not make a χ^2 cut, but simply choose the photon and the decay sequence in each event with the minimum χ^2 .

We consider three separate cases: (i) the track deposits < 300 MeV in the calorimeter, characteristic of a non-interacting π^+ or a μ^+ ; (ii) the track deposits > 300 MeV in the calorimeter, characteristic of an interacting π^+ ; (iii) the track satisfies our e^+ selection criteria [4]. Then we separately study the MM^2 distributions for these three cases. The separation between μ^+ and π^+ is not unique. Case (i) contains 99% of the μ^+ but also 60% of the π^+ , while case (ii) includes 1% of the μ^+ and 40% of the π^+ [5].

The overall signal region we consider is below MM^2 of 0.20 GeV^2 . Otherwise we admit background from $\eta\pi^+$ and $K^0\pi^+$ final states. There is a clear peak in Fig. 1(i), due to $D_s^+ \rightarrow \mu^+\nu$. Furthermore, the events in the region between $\mu^+\nu$ peak and 0.20 GeV^2 are dominantly due to the $\tau^+\nu$ decay.

The specific signal regions are defined as follows: for $\mu^+\nu$, $0.05 > \text{MM}^2 > -0.05 \text{ GeV}^2$, corresponding to $\pm 2\sigma$ or 95% of the signal; for $\tau\nu$, $\tau^+ \rightarrow \pi^+\bar{\nu}$, in case (i) $0.20 > \text{MM}^2 > 0.05 \text{ GeV}^2$ and in case (ii) $0.20 > \text{MM}^2 > -0.05 \text{ GeV}^2$. In these regions we find 64, 24 and 12 events, respectively. The corresponding backgrounds are estimated as 1, 2.5 and 1 event, respectively.

The $D_s^+ \rightarrow \tau^+\nu$, $\tau^+ \rightarrow e^+\bar{\nu}\nu$ mode is measured by detecting electrons of opposite sign to the tag in events without any additional charged tracks, and determining the unmatched energy in the crystal calorimeter ($E_{\text{CC}}^{\text{extra}}$). This energy distribution is shown in Fig. 2. Requiring $E_{\text{CC}}^{\text{extra}} < 400 \text{ MeV}$, enhances the signal.

We find $\mathcal{B}(D_s^+ \rightarrow \mu^+\nu) = (0.594 \pm 0.066 \pm 0.031)\%$; adding in the $\pi^+\bar{\nu}\nu$ gives $(0.638 \pm 0.059 \pm 0.033)\%$ as an effective rate. Our two measurements for $D_s^+ \rightarrow \tau^+\nu$ are $(8.0 \pm 1.3 \pm 0.4)\%$ and $(6.29 \pm 0.78 \pm 0.52)\%$ in the π^+ and e^+ modes, respectively. Finally $\mathcal{B}(D_s^+ \rightarrow e^+\nu) < 1.3 \times 10^{-4}$ (at 90% cl).

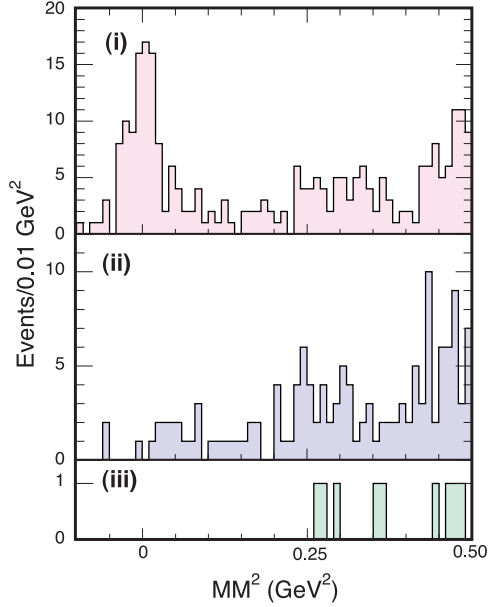


Figure 1. The MM^2 distributions from data using D_s^- tags and one additional opposite-sign charged track and no extra energetic showers for cases i-iii (see text).

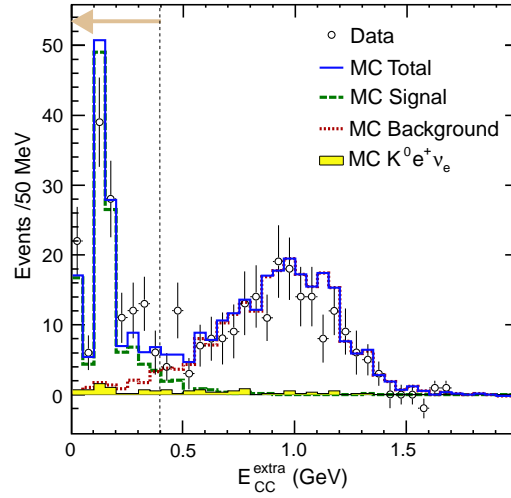


Figure 2. The extra calorimeter energy from data (points), compared with the Monte Carlo simulated estimates of semileptonic decays in general (dotted), the $K^0 e^+ \nu$ mode specifically (shaded), a subset of the semileptonics, and the expectation from signal (dashed). The peak near 150 MeV is due to the γ from $D_s^* \rightarrow \gamma D_s$ decay. (The sum is also shown (line).) The arrow indicates the selected signal region below 0.4 GeV.

3. Conclusions

We measure $\Gamma(D_s^+ \rightarrow \tau^+ \nu)/\Gamma(D_s^+ \rightarrow \mu^+ \nu) = 11.5 \pm 1.9$, consistent with the SM expectation of 9.72. Combining all three branching ratios determinations and using $\tau_{D_s^+} = 0.50$ ps to find the leptonic width, we find $f_{D_s} = 275 \pm 10 \pm 5$ MeV. Using our previous result [4] $f_D^+ = 222.6 \pm 16.7_{-3.4}^{+2.8}$ MeV, provides a determination of $f_{D_s^+}/f_{D^+} = 1.24 \pm 0.10 \pm 0.03$.

These results are consistent with most recent theoretical models. The most accurate unquenched lattice model of Follana *et al* [11] predicts $f_{D_s}/f_{D^+} = 1.162 \pm 0.009$ [12].

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